Chapter-wide learning goals:

1. Defend how climate science is conducted, including the use of observations and models.
2. Compare and contrast climate change research that focuses on the detection of trends in climatological data to that focusing on the attribution of causation to the observed changes.
3. Describe and discriminate between the direct and indirect ways in which climate change can affect Earth's biota.
4. Evaluate the strengths and limitations of the three distinct mechanisms by which a species may be able to successfully respond to climate change (i.e., acclimation, range shifts, and evolution).

Section 1: Why Does Climate Change Matter?

1. Discuss the relationship between temperature and performance across a range of biological scales, from enzymes to species.
2. Draw a graph illustrating the characteristic relationship between temperature and performance for some biologic process (e.g., enzyme activity, growth rate or locomotion).
3. Draw a graph illustrating how species richness tends to vary with temperature.

Section 2: Detecting Climate Change

1. Defend the conclusion that detection studies have found a clear, consistent warming trend since the Industrial Revolution in multiple components of the climate system, and that current mean global surface temperature is likely greater than at any point in past 2000 years.
2. Provide multiple examples of the different types of data climatologists rely on to demonstrate that, as predicted by basic physics, a warming signal has been detected in each component of the climate system (e.g., atmosphere, biosphere, cryosphere, hydrosphere, and lithosphere).
3. Defend the predictions climatologists have made about how various components of the climate system (i.e., atmosphere, biosphere, cryosphere, hydrosphere, and lithosphere) are expected to change as Earth warms.
4. Explain why, despite year-to-year variation in many data sets, climatologists have detected a clear signal in many components of the climate system over the past 150 years.
5. Explain the difference between climate and weather.
6. Explain why increasing the spatial resolution and expanding the temporal extent of various climate data sets (e.g., surface temperatures, arctic sea ice, and mean sea level) has improved the ability of climatologists to detect climate change.
7. Explain why a particular climatological data set (e.g., sea ice, ice sheets, precipitation, sea level, surface temperature) does (or does not) support the conclusion that Earth's climate has warmed over the past 150 years or so, despite large year-to-year variation in these data sets.
8. Provide examples of data supporting the conclusion that modern climate change (i.e., that occurring over the past 150 years) is unusual when compared to the past 2000 years.
9. Describe the general pattern of temperature change in the Northern Hemisphere over the past 2000 years.

Section 3: Earth's Climate and Climate Models

1. Defend the use of climate models by climatologists for attribution studies and for forecasting to a lay audience.
2. Use data to show that because Earth's energy budget is slightly out of balance, Earth is warming.
3. Analyze the effect carbon emissions have on Earth's climate, using a black body model.
4. Illustrate how a simple black body model can be used to investigate how differences in solar output, distance from the Sun, average albedo, and greenhouse gases affect a planet's mean global temperature.
5. Explain how the greenhouse effect warms a planet by trapping energy radiated from its surface, which would otherwise be lost to space.

6. Provide examples of how positive and negative feedbacks in Earth's climate system can accelerate or slow climate change, respectively.
7. Explain why climatologists are confident in the ability of global climate models/general circulation models, as a group, to recreate historic climate patterns.
8. Explain key differences between GCMs and simple black body climate models.

Section 4: Humans and Climate Change

1. Evaluate for a lay audience the evidence that humans are responsible for the changes in Earth's climate that have been observed since the Industrial Revolution.
2. Explain the relative ability of GCMs to recreate recent patterns of climate change, using models driven solely by natural forcings versus those driven by both natural and anthropogenic forcings.
3. Compare the drivers of modern climate change to those responsible for the glacial-interglacial cycles of the past 800,000 years.
4. Describe the general pattern of temperature change over the past 800,000 years.
5. Describe how atmospheric CO_2 has changed since 1950.
6. Persuade a lay audience that carbon emissions will need to be dramatically curtailed in order to limit the impacts of climate change on global ecosystems.
7. Contrast how mean global temperatures are likely to change over the next 100 years, depending on GHG emissions, as forecast by the various climate models used by the IPCC.
8. Summarize the key sources of uncertainty in climate models that limit their ability to produce accurate climate forecasts.
9. Explain how feedbacks can produce thresholds in the climate system that, once crossed, can produce rapid, unexpected changes that are hard to reverse.
10. Summarize the evidence suggesting that dramatic reductions in carbon emissions will be necessary to limit global temperature increases to 2 °C.
11. Describe projected spatial patterns of temperature change over the coming century.
12. Describe projected spatial patterns of precipitation change over the coming century.
13. Provide some examples of how the effects of climate change are expected to cascade through the climate system over the next century.

Section 5: Biological Consequences of Climate Change

1. Explain how changes in temperature and/or precipitation can directly affect individual performance and, consequently, population growth rates.
2. Use performance curves to illustrate why temperate ectotherms are expected to be less sensitive to climate change than tropical species.
3. Describe the two primary ways in which climate change can indirectly affect population performance through altered species interactions.
4. Provide examples of how phenological mismatches caused by climate change can reduce a population's growth rate (e.g., by altering interactions between predators and prey or between plants and their pollinators).
5. Provide examples of how changes in community composition caused by climate change can reduce a population's growth rate (e.g., if increasing the range of vector organisms increases the spread of disease).
6. Provide examples of how climate change can alter ecosystem function (e.g., the fertilization effect, ocean acidification, or altered disturbance regimes).
7. Explain how climate change can both directly and indirectly affect species by altering habitat availability (e.g., the broad ramifications of reduced sea ice).
8. Contrast the direct and indirect ways in which climate change can impact human populations.
9. Provide examples of how changes in temperature and/or precipitation can directly affect mortality rates of human populations.
10. Provide examples of how changes in temperature and/or precipitation can indirectly affect mortality rates of human populations (e.g., natural disasters, disease vectors).
11. Evaluate whether a species may be able to respond to climate change quickly enough to avoid extinction.

12. Summarize the characteristics that allow individuals of some species to acclimate to climate change more successfully than others.
13. Analyze the circumstances under which range shifts will enable populations to maintain performance as the climate changes.
14. Describe how and why species ranges are expected to shift as Earth's climate warms.
15. Provide examples of a population whose ranges have shifted in concert with warmer temperatures.
16. Explain how climate change may produce changes in community composition as member species respond independently.
17. Show how climate velocities can be used to identify species that may be unable to shift their ranges fast enough to track climate change.
18. Contrast the three factors that limit a population's ability to adapt to climate change via evolution by natural selection (i.e. the rate of environmental change, the population's genetic variation, and the species' generation time).
19. Provide examples of populations whose ability to handle warmer climates has evolved.